Effect of the Microalloying Elements on Nucleation of Allotriomorphic Ferrite in Medium Carbon-Manganese Steels

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It has been found that toughness and strength of steels can be improved simultaneously by transforming the austenite mainly in a fine acicular microstructure [1-4]. Consequently, there has been considerable effort towards maximizing the amount of acicular ferrite in the final microstructure. Several authors showed that the presence of a uniform layer of allotriomorphic ferrite along the austenite grain boundaries induces the transformation of austenite in acicular ferrite instead of bainite [5-10]. In this sense, allotriomorphic ferrite formation plays a particular and important role in influencing the development of acicular ferrite in mixed microstructures.

Titanium and vanadium microalloyed steels are of common use in the manufacture of automotive components [11-13]. Titanium is added with the aim of refining the microstructure through the inhibiting effect to grain coarsening exerted by small TiN precipitates [14-18]. Vanadium is selected due to its precipitation hardening capability, with a view to improve the toughness properties [19-23].

The purpose of the present study is to clarify experimentally the influence of V, Ti and V-Ti additions on the nucleation of allotriomorphic ferrite transformation and indirectly, on the development of the intragranular transformation of acicular ferrite in microalloyed forging steels.

(TABLE I)

Four medium carbon manganese steels were used in the present study. Their chemical compositions are shown in Table I. Three of them are microalloyed steels with different vanadium and titanium contents.

(TABLE II)

The isothermal decomposition of austenite has been analyzed by means of an Adamel Lhomargy DT1000 high-resolution dilatometer described elsewhere [24]. Its heating device consists of a very low thermal inertia radiation furnace. The heat radiated by two tungsten filament lamps is focussed on the specimen (cylindrical test pieces of 2 mm in diameter and 12 mm in length) by means of a bi-elliptical reflector. The temperature is measured with a 0.1 mm in diameter Chromel–Alumel (Type K) thermocouple spot welded to the specimen. Cooling is carried out by blowing a jet of helium gas directly onto the specimen surface. The helium flow rate during cooling is controlled by a proportional servo-valve. These devices ensure an excellent efficiency in controlling the temperature and holding time of isothermal treatments and fast cooling in quenching processes.

(Fig. 1)

As is well known, the prior austenite grain size (*PAGS)* exerts an important influence on the decomposition of austenite [25, 26]. Austenitization conditions were selected to achieve approximately the same *PAGS* in all the steels (~70 µm. See Table II). After austenitization, specimens were isothermally transformed at temperatures ranging from 973 to 873 K at different times and subsequently quenched under helium gas flow at a cooling rate of 200 K/s. Specimens were grounded and polished using standardized metallographic techniques. 2pct-Nital etching solution was used to reveal the ferrite microstructure by optical microscopy.

The incubation time is defined as the minimum time at which it is possible to detect some allotriomorphs nucleated on the austenite grain boundaries. This parameter has been measured by dilatometry and optical metallography. A detailed analysis of the dilatometric curve associated to the isothermal decomposition of austenite (relative change of length (dL/Lo) versus time (t)) (Fig. 1) allows one to determine an interval of time, Δt, in which it is more likely to find the incubation time.

Subsequent samples were isothermally heat treated at different holding times within the Δt interval. Finally, an accurate metallographic analysis of those samples determined a more precise incubation time at which some allotriomorphs appeared in the microstructure.

(Fig. 2)

Figure 2 shows the allotriomorphic ferrite nucleation curves for the five steels. Comparison of the nucleation curves of V, Ti and C-Mn steels suggests that vanadium delays the nucleation of this phase, whereas titanium speeds it up. However, according to the nucleation curve of V-Ti steel, it seems that the combined addition of V (0.13 wt-%) and Ti (0.039 wt-%) do not change the incubation time significantly as compared with C-Mn steels due to the opposite effect of both microalloying elements. On the other hand, the temperature at which the incubation time for allotriomorphic ferrite nucleation is a minimum (nose of the nucleation curves) is approximately the same for all the steels (~898 K). In this sense, V, Ti and V-Ti additions do not exert any influence on this temperature. Micrographs in Fig. 3 show the initial stages of allotriomorphic ferrite formation in the four steels investigated in this work.

(Fig. 3)

In conclusion, dilatometric and metallographic analyses allowed us to determine the nucleation curves of isothermally transformed allotriomorphic ferrite for a carbon manganese steel and three microalloyed steels. The experimental results have shown the influence of vanadium, titanium, and vanadium-titanium on the nucleation of this phase. It has been found that vanadium delays the isothermal formation of allotriomorphic ferrite, whereas titanium speeds it up. Likewise, the combined addition of V (0.13 wt-%) and Ti (0.039 wt-%) do not affect the incubation time significantly. However, none of them seem to have any influence on the temperature at which the incubation time for allotriomorphic ferrite is minimum.

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TABLE I Chemical compositions (mass %).

Steel	C	Mn	Cu	Cr	S	Si	Al	Ni	V	Ti	Mo
C-Mn	0.31	1.22	-	0.138	0.011	0.25	-	0.10	0.004	-	0.03
V	0.33	1.49	0.27	0.08	0.002	0.25	0.027	0.11	0.240	0.002	0.04
Ti	0.36	1.56	0.10	0.24	0.008	0.33	0.029	0.05	0.004	0.026	0.02
V-Ti	0.32	1.39	0.13	0.13	0.021	0.33	0.049	0.14	0.129	0.039	0.03

TABLE II Austenitization conditions

Steel	Temperature, (K)	Time, (s)	*PAGS*, (μm)
C-Mn	1473	120	70
V	1473	300	75
Ti	1523	180	65
V-Ti	1523	180	72

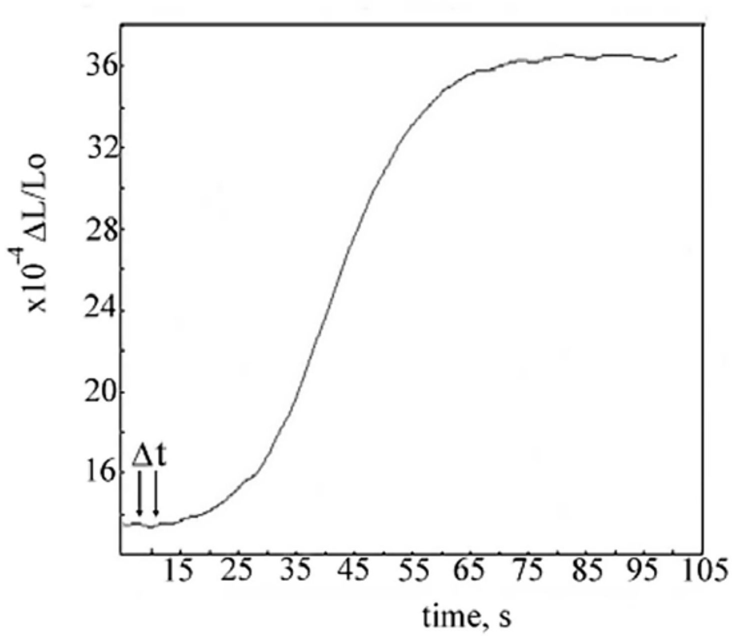

Fig. 1 Dilatometric curve ~~(relative change in length vs time)~~ obtained during isothermal decomposition of austenite into allotriomorphic ferrite.

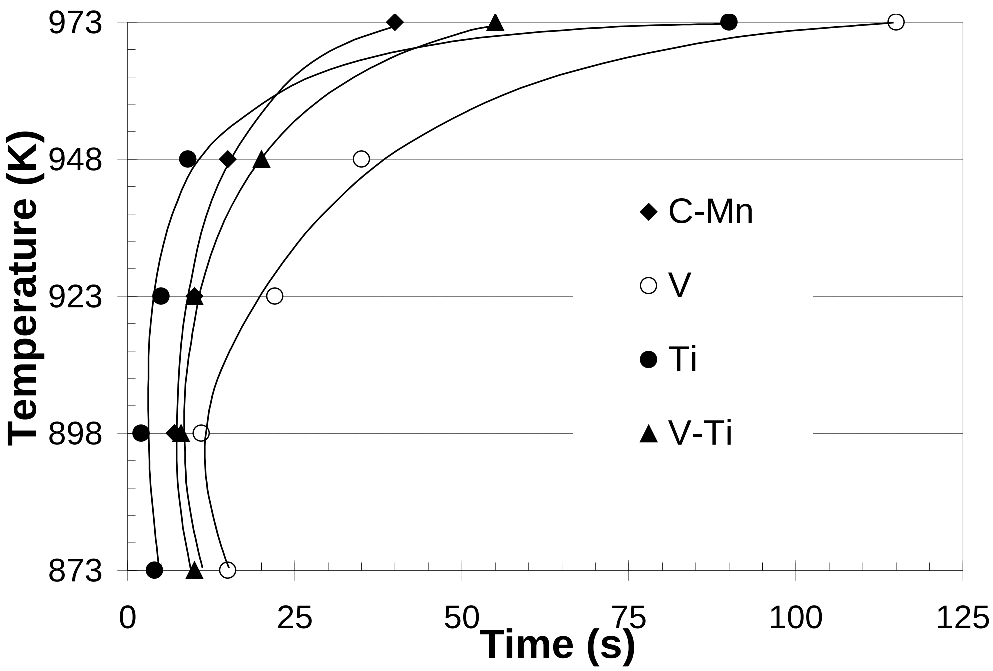

Fig. 2 Nucleation of allotriomorphic ferrite

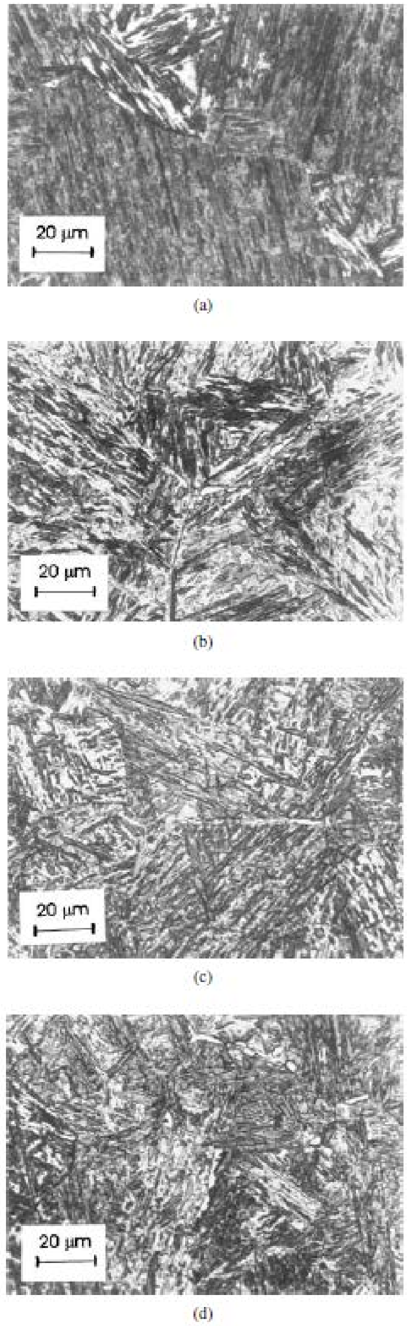

Fig. 3 Optical micrograph of the initial stages of the isothermal formation of allotriomorphic ferrite at 898 K in ~~the studied steels~~: a) C-Mn steel, t = 7s; b) V steel, t = 11s; c) Ti steel, t = 2s; d) V-Ti steel, t = 8s.